REMARKS

In response to the Official Action mailed November 7, 2002, Applicants amend their application and request reconsideration. In this Amendment claims 2, 4, 5, and 7 are cancelled and claims 11 and 12 are added. Accordingly, claims 1, 3, 6, 8-10, 11, and 12 are now pending.

An Information Disclosure Statement was filed January 8, 2003. Consideration is requested. The Information Disclosure Statement cited a foreign publication and identified it as a Japanese patent publication. It is obviously a Korean patent publication. A corrected PTO-1449 form is attached here.

The Examiner objected to the drawings as allegedly not showing eight specified elements appearing in claim 1. Applicants respectfully disagree with the Examiner's assertion. All of the elements of the examined claims do appear in the drawings of the patent application and therefore the objection should be withdrawn. Three of the cited elements no longer appear in any pending claim and do not need comment. The first four of the cited elements are so clearly understood by persons of ordinary skill in the art of liquid crystal displays that the explicit description of these environmental elements is not necessary. In the event the Examiner is unfamiliar with LCD technology, pages 226-232 and 242-245 of "Liquid Crystal Devices: Physics and Applications", Chigrinov (1999), are attached. Persons of skill in the art are familiar with the use of a matrix of intersecting signal and scanning lines to address pixels of liquid crystal displays. Particular attention is directed to pages 228 and 229 and Figure 3.9 of Chigrinov. These pages and the figure describe and show liquid crystal displays with display areas having crossing scanning and signal lines and column and row drives adjacent, but outside, the display areas on which a display appears. Chigrinov shows what was common knowledge in the art at the time the patent application was filed.

With regard to specific environmental elements mentioned in the claims pending upon entry of this Amendment, the display area of a liquid crystal display apparatus is described in the patent application with respect to Figure 28 as element 102. The Examiner's attention is directed to page 1, lines 8-20 with respect to that element and many of the other questioned elements. The drive circuit area of the liquid crystal display apparatus is described in the same passage of the patent application with respect to areas 115 and 116 of Figure 28.

The first and second lines, now referred to as first and second straight lines, are clearly illustrated in Figure 5 of the patent application. The three transistors 30 shown there have source, gate, and drain interconnections aligned along the first straight line. The three unnumbered transistors in the lower part of that figure likewise have source, gate, and drain interconnection aligned along what is referred to as the second straight line. Description is added to the specification, without the addition of new matter, describing what is shown in

Figure 5, at page 15 of the patent application. Those first and second straight lines were always shown in Figures 5-7 of the patent application and described in the patent application in a manner sufficient to inform one of skill in the art of the invention. Thus the rejection of the drawings with regard to this element is erroneous.

The last of the cited elements is the channel region of the driving transistors. Again, persons of skill in the art understand the structures of thin film field effect transistors that are employed in driving active matrix liquid crystal displays. The channel regions are specifically described in the patent application with regard to Figures 5-7 and the channel region 31 of a transistor embodiment that may be employed in the invention is illustrated in Figure 8 and in Figures 15-19 of the patent application. The corresponding descriptions appear at pages 17 and 18 of the patent application. The rejection must be withdrawn. In view of the remarks and the claim clarifications, no drawing corrections or amendments are necessary in response to the objection to the drawings.

The Examiner required the filing of a replacement specification with the lines of the specification double-spaced. The lines of the specification are double-spaced, in accordance with 37 CFR 1.52 (b)(2)(i). That regulation permits even closer spacing of the lines, i.e., 1.5 line spacing. Double line spacing means that a blank line appears between each pair of printed lines. (This document is double-spaced.) Since the specification is double-spaced and meets the applicable regulations, no substitute specification can be properly required nor is supplied.

It is not necessary to supply an additional description of "crossing of the signal lines and scanning lines" in the specification since that element does not appear in the claims. As already stated, the features "a drive circuit area" and "a channel region" are properly described in the specification. A description of the first and second straight lines is added to the specification without the addition of new matter.

Claims 1-7 and 10 were rejected as indefinite. Apparently claims 8 and 9 were also so rejected according to page 4 of the Official Action. However, whether there is such a rejection is not entirely clear. The rejection is respectfully traversed as to the claims now pending. Claim 1 has been amended for clarity. Most of the language cited as indefinite no longer appears in any pending claim and the language that does appear has been clarified, overcoming the rejection. Amended claims 8 and 9 provide antecedent basis for all terms.

Claims 1-10 were rejected as anticipated by Shiraki et al (U.S. Patent 5,844,538, hereinafter Shiraki). This rejection is respectfully traversed.

The invention concerns a particular arrangement of driving transistors for a liquid crystal display apparatus. In the claimed invention the gate interconnection to the gates of the driver transistors are located in respective zigzag patterns. Each zigzag pattern includes a straight line extending along a first direction and a second straight line extending along a second direction

not aligned with the first direction. Each pattern also includes an oblique straight line intersecting the first and second straight lines. The gates of the driver transistors are located on the first and second straight lines, and the channel regions of the driver transistors do not overlie the oblique straight lines. This arrangement is particularly important when the transistors include polycrystalline silicon elements made polycrystalline by laser annealing of amorphous silicon. As explained in the patent application, by providing this geometric arrangement, defects in the transistors caused by errors in the laser annealing process have reduced deleterious effects on the liquid display apparatus.

In citing Shiraki, the Examiner directed attention to Figures 23-26. Figure 26 of Shiraki is the only one of those figures that discloses any geometrical arrangement of field effect transistors in a liquid crystal display apparatus. It is apparent that those thin film transistors 107 are arranged along two parallel lines that are horizontal in Figure 26. A data signal line 104 seems to interconnect sources or drains of two field effect transistors 107 that lie along different parallel lines. Whether there may be gate interconnections in the structure of Figure 26 of Shiraki cannot be determined from the limited disclosure of that patent. What the geometry of the gate interconnections might be likewise cannot be determined from Shiraki.

Anticipation requires that a single reference unambiguously disclose every element of a claimed invention. Since there is no disclosure in Shiraki of gate interconnections, much less any suggestion for any specific geometry of any such gate connections, or the claimed gate interconnection patterns and driver transistors, it is apparent that Shiraki cannot anticipate any claim now pending.

Reconsideration and allowance of claims 1, 3, 6, and 10-12 are appropriate and earnestly solicited.

Respectfully submitted,

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JAW/tph

PATENT
Attorney Docket No. 400953/FUKAMI

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:

AOKI et al.

Application No. 09/729,086 Art Unit: 2871

Filed: December 5, 2000 Examiner: P. Akkapeddi

For: LIQUID CRYSTAL DISPLAY APPARATUS AND TFT PANEL

AMENDMENTS TO SPECIFICATION AND CLAIMS MADE IN RESPONSE TO OFFICE ACTION DATED NOVEMBER 7, 2002

Amendments to the paragraph beginning at page 15, line 16:

In the present embodiment, a gate interconnection 41 and the X direction driving circuit portion is arranged as shown in FIG. 5. As shown in FIG. 5, the width 34 of the channel region of each driving transistor 30 is ~~arranged~~ parallel to the gate interconnection. Each driving transistor 30 has its central portion electrically coupled by gate interconnection 41 and opposing sides electrically coupled by source interconnection 43 and drain interconnection 42. ~~At portions where~~ Where the driving transistor overlaps these interconnections, gate, source, and drain electrodes are ~~formed~~ located. Further, in the source electrode and the drain electrode, contact portions 37 are provided, which are electrically ~~conducted~~ connected to the source region 33 and the drain region 32 of the polysilicon film, respectively. Referring to FIG. 5, the channel regions of the three transistors 30 are aligned along a first straight line parallel to the channel width 34 and forming a first acute angle with the longer axis direction 25 of the laser beam. The first straight line intersects another straight line at a bent portion 90. That straight line of the bent portion 90 is parallel to the longer axis direction 25 of the laser beam. In FIG. 5, three additional unnumbered transistors in the lower part of the figure have respective channel regions aligned along a second straight line. The second straight line is oblique to the straight line of the bent portion 90, forms a second acute angle with the longer axis direction 25 of the laser beam, and forms an obtuse angle with the first straight line. The first and second straight lines, with the straight line of the bent portion 90, form a zigzag pattern that is repeated, as indicated in FIGS. 21 and 22, described below. As shown in FIG. 5, the channel ~~region is arranged not to~~ regions of the

transistors do not overlap the bent portion 90~~corresponding to a bent portion~~ of the zigzag pattern. This~~is to prevent~~ arrangement prevents an electric field concentration generated by the interconnections at this bent portion 90 from affecting the interconnections of the driving ~~transistor~~ transistors. When the channel portion overlaps the bent portion 90 where the electric field~~concentrates~~ is concentrated, a malfunction~~is possible~~ may occur, and hence such an arrangement must be avoided. A projection distance A, projected with respect to the direction of laser beam scanning, of the shift pitch between the three driving transistors arranged on~~one line~~ each of the first and second straight lines may be larger or smaller than the pitch P of the laser beam scanning. Typically, the channel width 34 is about 20 μm, the channel length 35 is about 5 μm, and the scan pitch P of the laser beam is about 15μm.

Amendments to the paragraph beginning at page 19, line 13:

In the second embodiment of the present invention, the direction of the width 34 of the channel region of each transistor is parallel to the direction 25 of the longer axis of the laser beam, as shown in FIG. 23. Referring to FIG. 23, the shift pitch A of three driving transistors arranged on a portion corresponding to~~a~~ one quarter of the wavelength, i.e., one quarter of the period of the repeating pattern, of the zigzag~~folded~~ line should preferably be larger than the scan pitch P of the laser beam,~~though~~ although it may be smaller. In the second embodiment, the first and second straight lines respectively consist of~~smaller folded lines~~ a plurality of parallel straight line segments, parallel to the respective channel widths 34 of the respective transistors, and oblique line segments oblique to and connecting pairs of the straight line segments.

Amendments to existing claims:

1. (Twice Amended) A liquid crystal display apparatus including:

a liquid crystal display~~,~~: and

a thin film transistor (TFT) panel, driving the liquid crystal display, and~~an opposing substrate, said TFT panel having a display area including a plurality of signal lines and a plurality of scanning lines crossing each other, a plurality of pixel transistors arranged where said signal lines and said scanning lines cross, and~~ having a driving circuit area~~including~~ on which a plurality of driving transistors are located, said driving transistors including respective sources, gates, and drains, and said driving circuit area including gate interconnections interconnecting gates of at least pairs of said driving transistors, wherein

~~a~~ said gate~~ interconnection for said driving transistors in said driving circuit area is arranged~~ interconnections are located along~~ a folded line~~ respective zigzag patterns, each zigzag pattern including a first straight line~~ linearly~~ extending along a first direction, a second straight line ~~linearly~~ extending along a second direction different from ~~said~~ the first direction, and a~~ bent portion connecting said~~ an oblique straight line intersecting and oblique to each of the first and second straight lines~~;~~, and

said gates of said driving transistors that are interconnected are ~~arranged along said~~ located on the first and second straight lines, ~~such that~~ and said channel regions of said driving transistors do not~~ overlap said bent portion when viewed two-dimensionally~~ overlie the oblique straight line.

3. (Twice Amended) The liquid crystal display apparatus according to claim 1, wherein each of~~ said~~ the first and second straight lines includes a~~ smaller folded line~~ plurality of parallel straight line segments joined by respective oblique straight line segments oblique to and intersecting the parallel straight line segments.

6. (Twice Amended) The liquid crystal display apparatus according to claim 1, wherein~~ a width of the~~ said channel~~ region~~ regions of said driving transistors~~ is~~ that are interconnected have respective widths that are parallel to~~ said~~ the first and second straight lines.

8. (Twice Amended) The liquid crystal display apparatus according to claim 1, wherein said driver transistors are polycrystalline silicon, crystallized from amorphous silicon by irradiation with a laser beam tracing stripes on said TFT panel, the stripes being spaced at ~~a~~ uniform interval on the TFT panel, and distance between a first of said driving transistors and a second of said driving transistors, neighboring and positioned nearest to the first driving transistor,~~ viewed from said display area,~~ is longer than~~ an~~ the interval of~~ pitch~~ the stripes that are traces of~~ scanning of~~ the laser beam~~ irradiation~~.

9. (Twice Amended) The liquid crystal display apparatus according to claim 1, wherein said driver transistors are polycrystalline silicon, crystallized from amorphous silicon by irradiation with a laser beam tracing stripes on said TFT panel, the stripes being spaced at ~~a~~ uniform interval on the TFT panel, and, in the channel region of each of said driving transistors,~~ a~~ distance between a corner of the channel region nearest to said display area and a corner of the channel region farthest from said display area~~, viewed from said display area~~,

is longer than ~~an~~ the interval of ~~pitch~~ the stripes that are traces of ~~scanning of~~ the laser beam ~~irradiation~~.

10. (Twice Amended) A thin film transistor panel for driving a liquid crystal~~, having a~~ display ~~area~~ including a plurality of ~~signal lines and a plurality of scanning lines crossing each other and a plurality of pixel~~ driving transistors ~~arranged where said signal lines and said scanning lines cross~~ located on a driving circuit area, said driving transistors including respective sources, gate, and drains, and said driving circuit including gate interconnections interconnecting gates of at least pairs of said driving transistors, wherein

~~a~~ said gate ~~interconnection for said driving transistors in said driving circuit area is arranged~~ interconnections are located along ~~a folded line~~ respective zigzag patterns, each zigzag pattern including a first straight line ~~linearly~~ extending along a first direction, a second straight line ~~linearly~~ extending along a second direction different from ~~said~~ the first direction, and ~~a bent portion connecting said~~ an oblique straight line intersecting and oblique to each of the first and second straight lines~~;~~, and

said gates of said driving transistors that are interconnected are ~~arranged along said~~ located on the first and second straight lines, ~~such that~~ and said channel regions of said driving transistors do not ~~overlap said bent portion when viewed two-dimensionally~~ overlie the oblique straight line.

PATENT
Attorney Docket No. 400953/FUKAMI

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:

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Application No. 09/729,086 | Art Unit: 2871

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For: LIQUID CRYSTAL DISPLAY APPARATUS AND TFT PANEL

PENDING CLAIMS AFTER AMENDMENTS MADE IN RESPONSE TO OFFICE ACTION DATED NOVEMBER 7, 2002

1. A liquid crystal display apparatus including:

a liquid crystal display: and

a thin film transistor (TFT) panel, driving the liquid crystal display, and having a driving circuit area on which a plurality of driving transistors are located, said driving transistors including respective sources, gates, and drains, and said driving circuit area including gate interconnections interconnecting gates of at least pairs of said driving transistors, wherein

said gate interconnections are located along respective zigzag patterns, each zigzag pattern including a first straight line extending along a first direction, a second straight line extending along a second direction different from the first direction, and a third straight line intersecting and oblique to each of the first and second straight lines, and

said gates of said driving transistors that are interconnected are located on the first and second straight lines, and said channel regions of said driving transistors do not overlie the third straight line.

3. The liquid crystal display apparatus according to claim 1, wherein each of the first and second straight lines includes a plurality of parallel straight line segments joined by respective oblique straight line segments oblique to the parallel straight line segments.

6. The liquid crystal display apparatus according to claim 1, wherein said channel regions of said driving transistors that are interconnected have respective widths that are parallel to the first and second straight lines.

8. The liquid crystal display apparatus according to claim 1, wherein said driver transistors are polycrystalline silicon, crystallized from amorphous silicon by irradiation with a laser beam tracing stripes on said TFT panel, the stripes being spaced at uniform interval on the TFT panel, and distance between a first of said driving transistors and a second of said driving transistors, neighboring and positioned nearest to the first driving transistor, is longer than the interval of the stripes that are traces of the laser beam.

9. The liquid crystal display apparatus according to claim 1, wherein said driver transistors are polycrystalline silicon, crystallized from amorphous silicon by irradiation with a laser beam tracing stripes on said TFT panel, the stripes being spaced at uniform interval on the TFT panel, and, in the channel region of each of said driving transistors, distance between a corner of the channel region nearest to said display area and a corner of the channel region farthest from said display area, is longer than the interval of the stripes that are traces of the laser beam.

10. A thin film transistor panel for driving a liquid crystal display including a plurality of driving transistors located on a driving circuit area, said driving transistors including respective sources, gate, and drains, and said driving circuit including gate interconnections interconnecting gates of at least pairs of said driving transistors, wherein

said gate interconnections are located along respective zigzag patterns, each zigzag pattern including a first straight line extending along a first direction, a second straight line extending along a second direction different from the first direction, and a third straight line intersecting and oblique to each of the first and second straight lines, and

said gates of said driving transistors that are interconnected are located on the first and second straight lines, and said channel regions of said driving transistors do not overlie the third straight line.

11. The liquid crystal display apparatus according to claim 10, wherein each of the first and second straight lines includes a plurality of parallel straight line segments joined by respective oblique straight line segments oblique to the parallel straight line segments.

12. The liquid crystal display apparatus according to claim 10, wherein said channel regions of said driving transistors that are interconnected have respective widths that are parallel to the first and second straight lines.

Liquid Crystal Devices: Physics and Applications

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can be individually selected by a simultaneous application of a positive voltage to the column electrode and the negative voltage to the row electrode (see Figure 3.7). However, the FED technology is only in the development stage. Despite the fact that the main patents appeared more than 10 years ago, there still is no large-scale FED production and the commercialized monochrome FED panels are rather expensive (3–5 times more expensive than corresponding LCD panels). One of the problems, which still remains unsolved, is spoiling of the microtips of the cathode by impurities existing in the interlayer gap. However, in the near future a considerable increase of the FED share of the market is expected (see Table 3.1). One of the recent elegant implementations of the FED construction includes a fabrication of *n*-type silicon emitter tips on the drain of an otherwise standard MOSFET [15]. A considerable improvement of emission-current stability was obtained.

3.1.2 History of LCDs

Liquid crystals have been known since the works of Reinitzer and Lehmann were published more than 100 years ago, and although their remarkable electro-optical properties were investigated in the early works of Freedericksz, Zwetkoff, Oseen, Frank, Saupe, and other outstanding scientists, the interest in the display application of liquid crystals appeared only at the end of the 1960s [16]. Increasing interest in the display application of LCDs is probably due to the activity of the Heilmeier group, who proposed "dynamic scattering effect" in LCs with a negative dielectric anisotropy (see Figure 3.8).

The effect is characterized by a strong scattering of light when the electric field exceeds a certain threshold value. The effect has been well known since

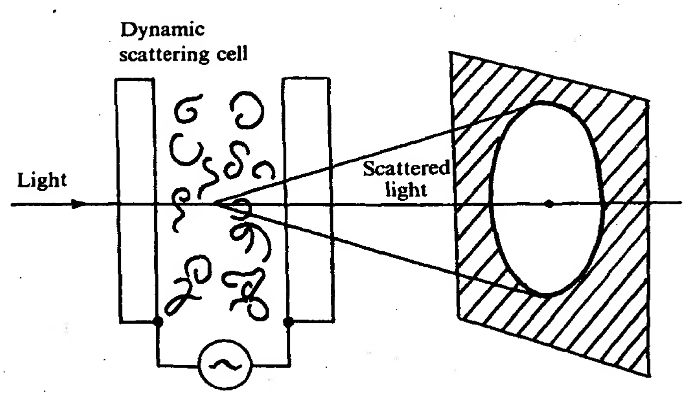


Figure 3.8 Dynamic scattering of light-the effect of the first generation of LCDs.

the early publications of Freedericksz and Bjornstahl [16, 17]. However, the first room temperature LC mixture, MBBA (4-methoxybenzylidene-4′-n-butylaniline), suitable for dynamic scattering LC applications only appeared in 1969, synthesized by American researchers Kelker, Scheuerle, and Minihg [17].

At the end of the 1960s, two more electro-optical effects in LCs for display applications were discovered: a guest-host effect in LC mixtures with dichroic dyes (Heilmeier and Zanoni) and a cholesteric-nematic transition in electric field (Wysocki, Adams, and Haas). The first generation of LCDs based on these effects had obvious drawbacks in comparison with LEDs, which dominated during this period. The operating voltages and power consumption were rather high, and the contrast and viewing properties could not compete with these ones of LEDs. It was partially due to a poor choice of LCs and dichroic dyes available for display applications. One of the major disadvantages was a poor multiplexing capability, which is an absolutely necessary feature of high information content, passively addressed LCDs.

The first TN-LCDs based on twist effect appear in the early 1970s (Schadt, Helfrich, and, later, Fergason). Twist effect has a number of advantages over the previously known electro-optical LCD modes. TN-LCDs provide black-and-white switching under low controlling voltages with relatively fast response times and low power consumption. As a field mode, twist effect makes possible a sufficiently long lifetime of TN-LCDs due to the absence of electrochemical degradation of LC material. A matrix-addressing technique was developed, which made it possible to produce low-cost LCDs with more than 30 addressed pixels (see Figure 2.15). A relatively steep transmission-voltage curve of TN-LCD makes it possible to address approximately 64 rows of display panel. However, TN-LCDs with a larger number of rows exhibit poor contrast and very narrow viewing angles. Thus, only small and medium-size TN-LCDs become possible.

LCDs with a high information content were definitely realized with the discovery of supertwist mode in 1984 by Scheffer and Nehring. STN-LCDs provide passive addressing up to 512 rows due to the increased steepness of the transmission-voltage characteristic (TVC) and wider viewing angles. However, initially STN-LCDs were very slow with monochromatic switching and a small contrast ratio. Later, phase-compensated (FSTN) and double STN (DSTN) LC cells appeared with black-and-white switching together with color STN modules having RGB filters for color production [18] (see Figure 3.9(a)). All the new methods of simultaneous row and column addressing, such as active addressing and multiline selection, considerably improve response times and contrast ratios of STN-LCDs, opening the way to their applications in video monitors and desktop computers (see Figure 2.27). STN-LCDs with a

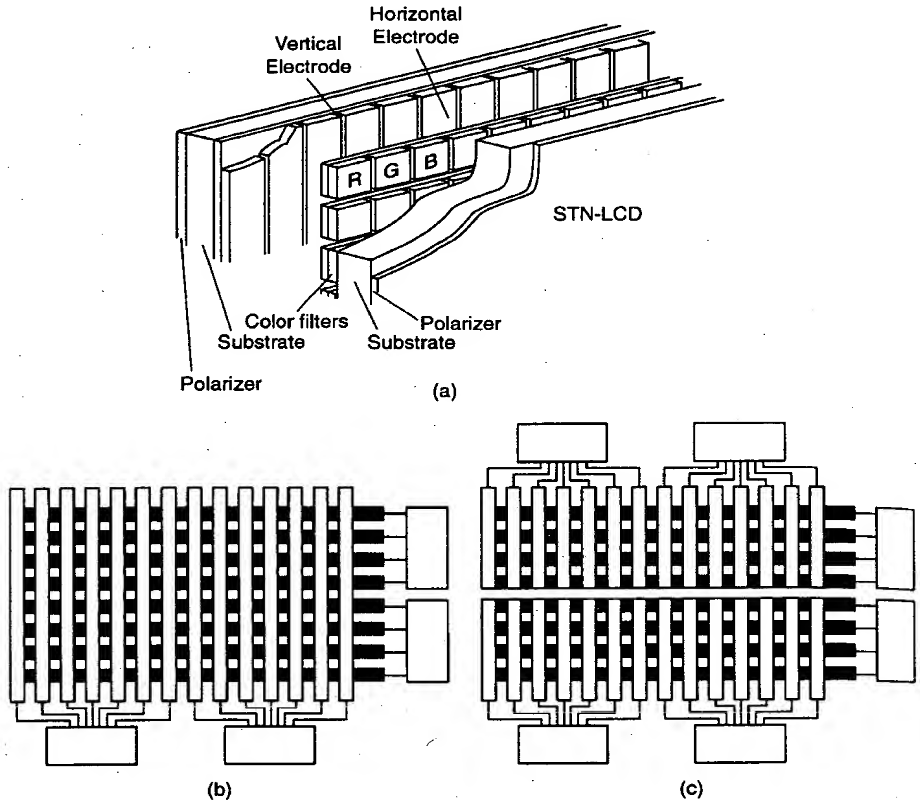


Figure 3.9 Color-matrix-addressed STN-LCDs: (a) structure with RGB filters; (b) standard STN screen with row and column drivers; (c) dual-scan STN-LCD with a twofold increase in the number of column drivers.

dual scan (i.e., doubled number of column drivers) allow a twofold reduction of the number of the addressed rows per one frame period (see Figure 3.9(c)). This modification considerably improves STN-LCD image quality, as an extremely high steepness of the TVC is no longer needed.

New possibilities are opening up in the most advantageous technology of active-matrix addressing displays. The main types of high information content LCDs used in personal computers, portable TV, and video monitors are based on this technology. As mentioned above, the principle of matrix addressing is evidently beneficial, as it allows us to diminish the number of electrical contacts in the driving circuit by as much as $mn/(m + n)$ times, where m and n are the number of columns and rows, respectively (see Figure 2.15). In active-

matrix-addressed displays, each pixel is connected to a nonlinear element so that the required level of voltage is maintained during the whole frame period, thus providing the necessary level of contrast (see Figure 3.10). Metal-insulator-metal (MIM) diodes or thin-film transistors (TFT) are used as nonlinear elements. The color is provided by RGB filters. Active-matrix-addressed LCDs (AM-LCDs) were first produced 25 years ago (Brody) and became the dominant LCD type in the beginning of 1995, when their price unexpectedly and drastically fell. Thus, the ratio TFT AMLCD-STN-LCD for the most important application in notebook PCs changed from 3:7 in 1995 to 7:3 in 1996 [18].

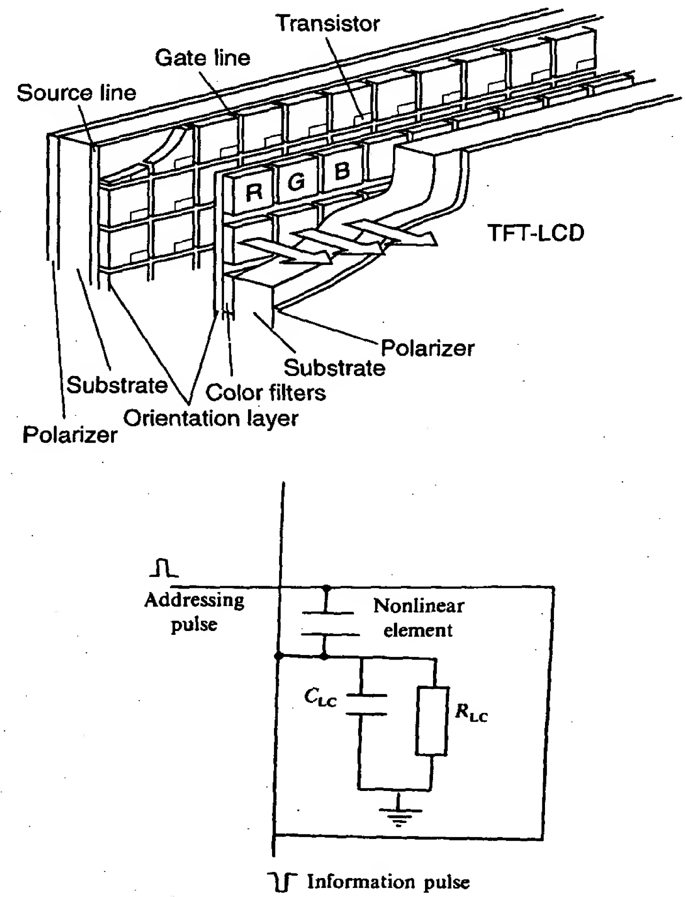


Figure 3.10 Active-matrix-addressing liquid crystal display with thin-film transistors used as nonlinear elements.

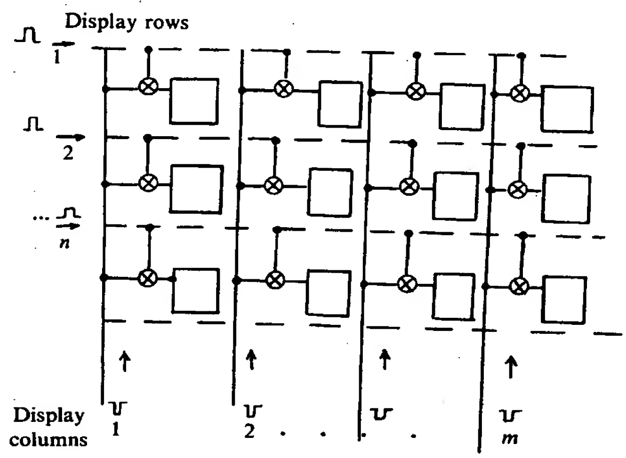


Figure 3.10 (continued).

In 1994, AM-LCDs had a small screen size of about 9.5 inches (9.5 inch) in diagonal in VGA standard (640 × 480 pixels), while in 1997, AM-LCDs with a 13.3-inch screen size with XGA (1024 × 768 pixels) resolution appeared on the market (see Figure 3.11) [19]. Power consumption of AM-LCD has been also reduced from 10–15W down to the 3–4W range. Further visible decrease of the TFT AM-LCDs cost will almost close the question of what type of the FPD is the most suitable for portable PCs.

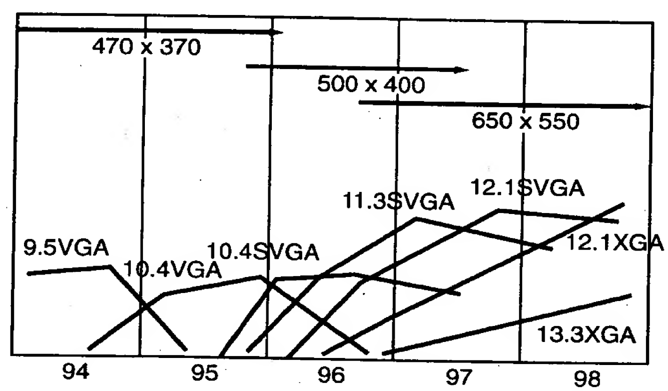


Figure 3.11 Growth of AM-LCD application in notebook PC market [19]. The diagonal size (inches) and resolution of AM-LCDs are shown: VGA-640 x 480 pixels, XGA-1024 x 768 pixels.

Finally, let us mention that in parallel with STN-LCD and AM-LCD types, the new LCD prototypes were proposed, including ferro- and antiferroelectric LCDs [20], reflective cholesteric LCDs [21], vertically aligned LCDs (Stanley), plasma-addressed LCDs (Tektronix), bistable nematic and chiral nematic LCDs [19], and so forth. However, these type of LCDs are only in the prototype stage and not yet in mass production.

3.1.3 LCD Applications

LCDs in mass production appeared in the market in the early 1970s, immediately after the discovery of twist effect, which during this time was used in 99% of all LCDs. First, LCDs were applied in wrist watches, calculators, electronic games, displays of cellular phones, photo and video cameras, measuring equipment in science and medicine, car dashboards, translators, small information boards in trains and buses, airports and gasoline stations, and so forth. The largest LCD growth rate occurred when LCDs with high information content were put into mass production. The market for these LCDs became very broad, ranging from the screens of portable computers, word processors, small TV, and video-monitors, camcorders and personal digital assistants (PDAs) to desktop PCs and workstations, large size direct view TVs, projection TVs, and car navigation systems. However, the market for low information content LCDs is still important. For example, the number of LCDs in cellular phones is expected to double in 1999 as compared to 1996 [18].

The market for notebook PCs is expected to achieve 20 million units by the year 2000. Larger size (12.1 inch ⇒ 13.3 inch), higher resolution (SVGA ⇒ XGA), wider viewing angles, lower power consumption, faster response operating times, and broader operating temperature range are the main tendencies in LCD developments for notebook PC applications.

The market for desktop PC and workstation monitors will grow from 50 million in 1995 to 80 million by the year 2000; that is, this market is about 4–5 times larger than notebook PC market [18]. The most popular CRT sizes for the desktop computer screens are 14–15 inch, but 17-inch are becoming more attractive for the customers. The corresponding LCD sizes are 12–15 inch, and it is expected that 13–14-inch LCDs could reach a 5%–10% share in the desktop PC market by 2000. The improvement of viewing angles will be the "hot" R&D topic for LCDs in this application.

The competition of AM and STN LCDs takes place in the desktop PC market. STN-LCDs are at least 2–3 times cheaper than AM-LCDs, and the new developments of the Sharp Company, declared recently [22], are a big step in this direction. The review of the last developments in notebook and

desktop PC LCDs is shown in Table 3.4 [22, 23]. As seen from Table 3.4, both AM and STN-LCDs have excellent characteristics as PC monitors.

For direct TV applications with more than 40-inch screens, CRTs cannot be used due to their weight and size. A large 40-inch TFT AM-LCD with SVGA format, consisting of two AM-LCDs of a smaller size, was recently demonstrated by Sharp [24]. This type of LCD application must be competing with PDP panels. One of the possibilities to compete is the application of plasma-addressed liquid crystal (PALC) technology, developed by Tektronix in 1990 [25]. PALC technology is a new method of active addressing of LCD panel (see Figure 3.12). Instead of 2,000–3,000 transistors for each scanning line (see Figure 3.10), a PALC device requires only two parallel electrodes and a gas to cover one switching element for one scanning line. The ionized gas (plasma) in long semicylindrical channel, when the latter is activated, goes to the open state of the line, thus making it possible to write information to the column (data) pixels. The PALC system disadvantage is a too-high controlling voltage (about 350V). Sony made a 25-inch TV based on this technology and is considering to making large-screen high definition TVs (HDTVs), according to the market demands.

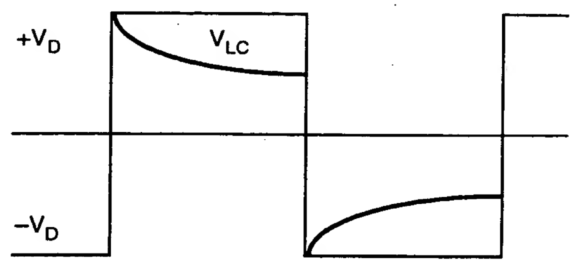
AM-LCD projection devices have certain advantages in comparison with CRT-based ones [26]. They are easier to use and set up, the light beam convergence is more stable, the luminance is higher, and the pictures are crisper. The modern AM-LCD projection systems contain more than 1.5 millions pixels, providing more than 16 millions colors. The viewing angles are wide. The LCD projection devices are compatible with personal computers and handle the video signals from all TV systems. Several electro-optical LC modes, such as twist nematic (TN), polymer dispersed LC (PDLC), and electrically controlled birefringence (ECB) can be used in projection devices with increased brightness.

Smaller computers such as personal digital assistants (PDAs) and organizers can utilize smaller size and resolution screens, such as STN-LCDs, in transmissive and low-power reflective modes, including reflective color STN.

3.2 Active-Matrix Addressing LCDs

3.2.1 Two-Terminal Nonlinear Devices

As we already mentioned, the principle of active addressing includes individual control of each LCD screen pixel by a nonlinear element specially attached to it (see Figure 3.10). AM-LCDs apply two- or three-terminal devices. The two-terminal devices are either thin-film diodes (TFDs) or metal-insulator-metal (MIM) elements. Let us consider first MIM-addressed LCDs [27, 28].



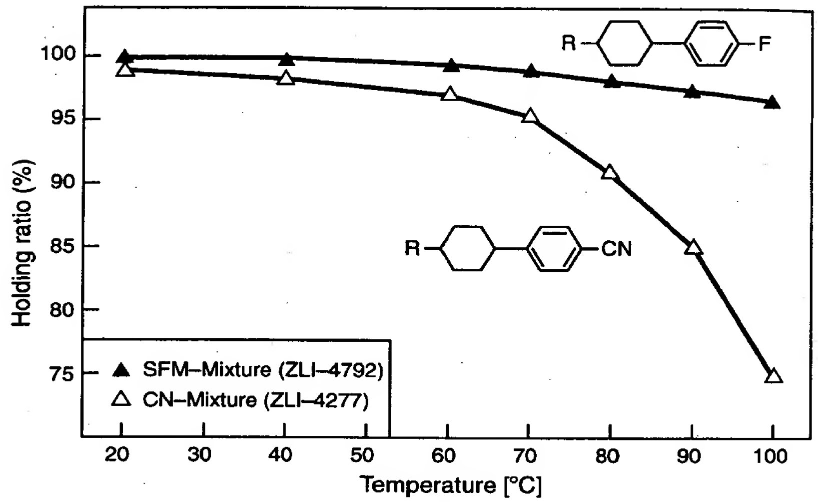


Figure 3.16 Holding ratio of TFT AM-LCD and its correlation with the LC molecular structure [29]: (a) definition of the holding ratio as V_{LC}/V_D voltage, where V_D is the voltage after charging the LC pixel and V_{LC} is the voltage at the LC pixel at the end of the frame time, when a new portion of charge is going to come; (b) temperature dependence of holding ratio for two different LC structures.

also causes a serious problem, which may be solved only by a more precise control of the fabrication steps.

3.2.2.3 Fabrication

Amorphous silicon (α-Si) is the most used material for TFT application. It can be deposited at low temperatures (≈300°C), which means that inexpensive glass can be used. The drawbacks of this material are a low electron mobility

(0.2–0.5 $cm^2/V/sec$) and the necessity to use light shields as the material is highly photosensitive. As the mobility is low, to speed up the LC pixel charging, the large source-drain channels must be used (see Figure 3.17) with 10–20 μm for length and 100–140 μm for width. For the pixel size of about 220–250 μm, the "dead" area, where α-Si TFT is placed, could be more than 50%. Typically the "working" part of the LC pixel (aperture ratio) occupies from 50 to 75% [27].

The fabrication of TFTs is more difficult, than in case of two-terminal driving devices. One of the possible TFT constructions is shown in Figure 3.17 [27]. The steps, included are as follows:

1. Deposition and patterning of the gate metal.
2. Deposition of gate insulator (Si_3N_4), amorphous silicon (α-Si) and a doped n + α-Si.

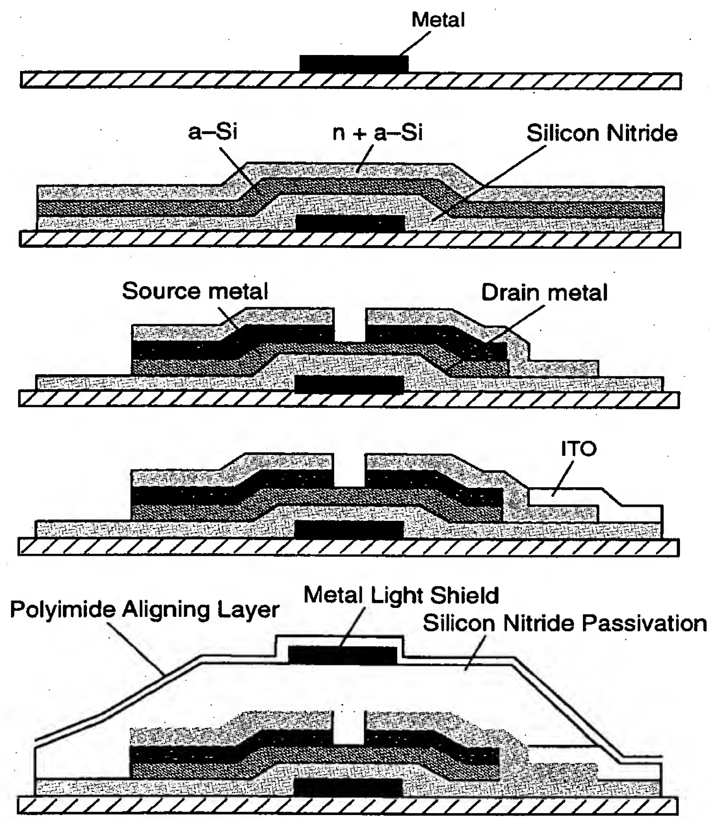


Figure 3.17 Fabrication of thin-film transistor on the glass substrate [27].

3. Patterning with photolithography of α-Si and $n + \alpha$-Si.
4. Deposition and patterning of the source and drain metal.
5. Deposition and patterning of ITO electrodes.
6. A coating of the entire substrate with Si_3N_4.

The layers of TFTs in Figure 3.16 are prepared with thin-film processes such as sputtering, PECVD (plasma-enhanced chemical vapor deposition), conventional photolithography, and pattern generation by wet chemical etching or reactive ion etching. Besides the well-known sputtering, the most important processes are PECVD, plasma etching, and the endpoint control during plasma etching [28]. The fabrication and different models of TFT elements are considered more in detail in [27, 28].

3.2.2.4 New Possibilities of TFT Fabrication: Polycrystalline Silicon (Poly-Si) Materials

Poly-Si TFTs with an increased electron mobility up to 440 $cm^2/V/sec$ are generated at high process temperatures above 550°C for which the expensive quartz-glass is required. They allow for small channel areas of 2 μm × 2 μm for the high pixel densities that are needed in displays in camcorders, light valves in projectors, or document type displays with a pixel size about 20–50 μm. The small size of Poly-Si TFTs (down to 5 × 5 microns) results in the higher aperture ratios of AM-LCDs. These structures are not sensitive to light and do not need special light shields as in the α-Si case.

However, there are certain shortcomings of Poly-Si applications [27], such as: (1) large area Poly-Si TFTs (>12 inch in diagonal) is difficult to obtain; (2) costly substrates due to the increased temperature of the deposition and recrystallization—the lowest temperature of fabrication is about 500°C was reported [30]; (3) larger off leakage current and more expensive fabrication techniques, including ion implantation.

The fabrication is similar to the α-Si-fabrication, except for the accuracy of the photolithographic patterning processes, where micron and submicron resolution are required. Special measures must be also undertaken to diminish the off current, which is higher in Poly-Si TFTs due to the increased mobility of the electrons. The measures include (1) the application of the additional capacitor in parallel with LC element; (2) creating special depletion barriers by doping used Poly-Si; (3) making dual gate Poly-Si TFT structures [27].

The mobilities of Poly-Si-TFTs are high enough to realize all drivers, including the fast row and column video drivers. These drivers can be placed

ɔf α-Si and $n + \alpha$-Si.
ource and drain metal.
electrodes.
ith Si_3N_4.

prepared with thin-film processes nced chemical vapor deposition), generation by wet chemical etching wn sputtering, the most important he endpoint control during plasma nodels of TFT elements are consid-

ion: Polycrystalline Silicon

mobility up to 440 $cm^2/V/sec$ are ɔve 550°C for which the expensive for small channel areas of ies that are needed in displays in locument type displays with a pixel ze of Poly-Si TFTs (down to re ratios of AM-LCDs. These struc- : need special light shields as in the

nings of Poly-Si applications [27], 12 inch in diagonal) is difficult to reased temperature of the deposition ature of fabrication is about 500°C rrent and more expensive fabrication

i-fabrication, except for the accuracy esses, where micron and submicron must be also undertaken to diminish i TFTs due to the increased mobility (1) the application of the additional 2) creating special depletion barriers l gate Poly-Si TFT structures [27]. e high enough to realize all drivers, › drivers. These drivers can be placed

along the edges of the glass plates. The concept of integrated drivers is a great advantage of Poly-Si TFTs [27, 28].

The other TFT materials are cadmium selenide (CdSe), germanium (Ge), tellurium (Te), and others [27]. The advantage of these materials is a higher mobility than that of amorphous Si together with a lower temperature of deposition than required for Poly-Si. However, these TFTs are mostly in the development stage.

3.2.2.5 Structure and Fabrication of TFT-AM-LCD

A cross section of the completed TFT-AM-LCD is shown in Figure 3.18 [31]. We can see that the total construction includes TFT, placed on one of the glass substrates, which occupies from 50% to 25% of the active display area. The process of TFT fabrication has already been described. The glass is protected by a sodium barrier film (SiO_2) from the charge injection from the glass. The LC cell contains orientation layers on both sides of the substrates and spacers to maintain the uniform gap between the substrates. Let us mention that the usual rubbing methods of the orientation layer treatment are not convenient on the substrate, where TFTs are placed, especially for a small size of pixels. Thus, the above-mentioned photoaligning technique (see Figure 1.30) looks rather promising as it makes it possible to avoid electrostatic charges and damage to TFT elements. The other substrate contains the color RGB filters together with a black mask. The color filters development will be considered below. The total sandwich is covered by polarizers from both sides, which sometimes are combined with phase retardation plates to improve the viewing angles and the contrast of the LCD.

At the beginning of the process, the two substrates are formed—one with RGB color filters (color plate) and another with TFT elements (active plate). Both substrates are covered by sputtering with transparent ITO electrodes. After this, the substrates are cleaned and coated with aligning layer (e.g., by

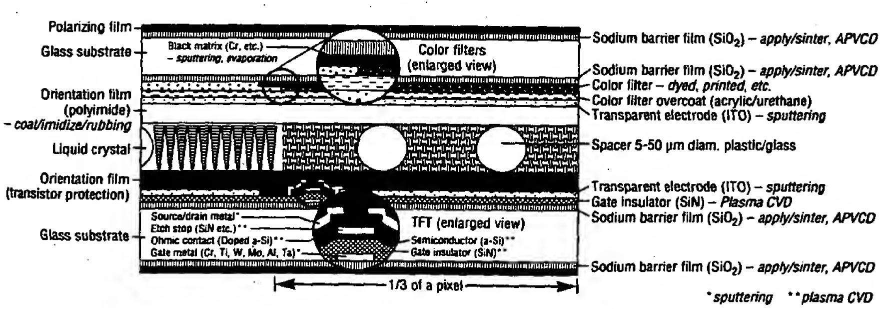


Figure 3.18 Cross section of TFT-AM-LCD [31].